



Soil Quality Indicators

Chemical Indicators and Soil Functions

What is soil quality? Concise definitions for soil quality include “fitness for use” and “the capacity of a soil to function.” Combining these, soil quality is the ability of a soil to perform the function necessary for its intended use. Doran and Parkin (1994) defined soil quality as the capacity of soil to function within ecosystem and land-use boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health. Others have defined it as the soil’s capacity or fitness to support crop growth without resulting in soil degradation or otherwise harming the environment or as, more simply, fit for purpose (Oliver et al., 2013). Soil quality is often perceived as an abstract characteristic of soils, which cannot be defined because it depends on external factors, such as land use and soil management practices, ecosystem and environmental interactions, and socioeconomic and political priorities (Pankhurst et al., 1997). Soil quality is assessed with respect to specific soil functions (Larson and Pierce, 1994). However, soil functions themselves cannot be directly measured. Selected physical, chemical, and biological properties of soil are used instead to quantify soil quality functions related to specific goals. Those soil properties are called soil quality indicators.

Soil quality indicators are soil measurements that can represent the conditions of the system or the soil’s ability to perform system functions. Attributes of a good indicator are sensitivity to change, ease of measurement and interpretation, and repeatable methodology and reversibility so that both improvement and decay can be monitored.

Different chemical indicators widely used are related to the respective basic functions they measure. Those basic functions include: (1) promoting biodiversity activity and productivity, (2) filtering, buffering, degrading, and detoxifying organic and inorganic materials, (3) controlling the regulation and partition of water and solute flow, (4) cycling carbon and nutrients, and (5) providing physical stability for plants and animals as well as providing support for structures associated with human habitats. See Table 1.

The chemical components and properties of the soil affect many reactions and processes occurring in the soil environment. For example, soil pH controls the solubility and mobility of heavy metals, such as Al, Fe, Mn, Cu, and Zn, and nutrients, such as phosphorus. It also controls the toxicity of many heavy metals. It also affects percent saturation, soil buffering capacity, cation-exchange capacity (CEC), and soil biological properties like microbial growth and diversity (bacteria, except acidophil species, are very sensitive to low pH, in contrast with fungi). Like physical and biological indicators, chemical indicators are sensitive to soil management and natural disturbances. Tillage practices (e.g. continuous till, conservation till, and organic and inorganic amendments) may change the levels of soil reaction (pH), as well as nitrate, TOC, and P content. Continuous cultivation without the correction of pH by liming can lead to soil acidification. A continuous application of acidifying fertilizers, such as ammonium nitrate (NH_4NO_3), ammonium sulfate (NH_4SO_4), and elemental sulfur (S), to alkaline soils lowers soil pH values. Leguminous crops can slightly acidify the soil. Irrigation water with high amounts of salt concentrations can result in soil salinization (high EC values).

In addition to the indicators shown in Table 1, many other soil chemical properties, including CEC, percent base saturation, and exchangeable sodium percent (ESP), have been suggested as potential soil quality indicators. These properties, however, are only measurable in laboratory settings and only a small number of chemical

properties are directly measured in the field. So few chemical properties are measured in the field because data measured under field conditions exhibit high variations, such as variations from one data point to another (micro-relief variation), seasonal variation (water content), soil type (texture), etc. Because field variations make determining accurate data difficult, several measurements across the field (i.e., a large number of samples) may be required to attain less variable data for many chemical properties.

The chemical indicators that can be directly measured in the field are soil pH, EC, nitrate-nitrogen, and phosphorus-phosphates (measured by P test strip particularly in the Midwest). Reactive carbon is measured in the laboratory and field office, respectively. Although this indicator is related to organic matter, chemical reagents used in the procedure can dissolve carbon associated to the mineral fraction of soil sample.

Table 1 shows how different chemical indicators are correlated with various soil quality functions. As shown in the table, an indicator can be related more than one function.

Table 1. Chemical indicators as related to soil quality functions. (The number of asterisks indicates the strength of the relationship between the indicator and the function. For example, 3 asterisks mean that the chemical is a major indicator and 1 or 2 asterisks mean that the chemical is a minor indicator.)

Soil Quality Indicator	Soil Function				
	Sustain biological diversity, activity, and productivity "D"	Regulate and partition water and solute flow "W"	Filter, buffer, degrade, detoxify organic and inorganic materials "F"	Store and cycle nutrients and carbon "N"	Physical stability and support for plants and structures associated with human habitation "S"
Phosphorus ^b	★	★	—	—	—
Reactive Carbon ^a	★★	★	★★★	★★	★★
Soil Electrical Conductivity ^b	—	★★★	—	—	—
Soil Nitrate ^b	★	★	—	—	—
Soil pH ^{b,d}	★★	★★★	★★★	★★★	—

^a laboratory/office method

^b field method

^c time consuming

^d simple visual observation

Soil reaction (pH) generally refers to the degree of soil acidity or alkalinity. Chemically, it is defined as the \log_{10} hydrogen ions (H⁺) in the soil solution. (H⁺) represents activity of hydrogen ions in solution, not concentration of hydrogen ions, which is represented as [H⁺]. The pH scale ranges from 0 to 14; a pH of 7 is considered neutral. If the pH value is greater than 7, the solution is considered basic or alkaline; if it is below 7, the solution is acidic. It is important to recognize that because the pH scale is in logarithmic units, a change of just a few pH units can induce significant changes in the chemical environment and sensitive biological processes. For example, a soil with pH of 5 is 10 or 100 times more acidic than a soil with pH of 6 or 7, respectively. Sources of H⁺ ions in soil solution include carbonic acid produced when carbon dioxide (CO₂) from decomposing organic matter, root respiration, and the soil atmosphere is dissolved in the soil water. Other sources of H⁺ ions are root release, reaction of aluminum ions (Al³⁺) with water, nitrification of ammonium from fertilizers and organic matter mineralization, reaction of sulfur compounds, rainwater, and acid rain. Certain soils are more resistant to a drop or rise in pH (buffering capacity). Therefore, the lime requirement, which is the quantity of limestone (CaCO₃)

required to increase the pH of an acid soil to a desired level, must be determined specifically for each field before amending the soil. Some crops grow well on or tolerate acid soils, others grow well on or tolerate alkaline soils. The majority of crops grow in soils with pH between 6 and 7.5; few plants prefer, however, acid or alkaline soils.

Reactive carbon (RC), also known as permanganate oxidizable carbon (POxC) or active carbon, is a fraction of the soil organic matter (SOM) pool of C that is oxidizable in the presence of potassium permanganate in solution. Carbon oxidized by this compound includes the C most readily degradable by microorganisms as well as that bound to soil minerals, making RC interpretation somewhat difficult. Because of this association to the mineral fraction, RC is considered a chemical indicator, not a biological indicator. Nevertheless, a recent research project conducted across a range of environments and management conditions (12 studies) showed that POxC was significantly related to particulate organic carbon, soil microbial biomass carbon (BMC), and, in one study, soil organic carbon.

The residence time of RC is estimated to be 2 to 5 years, in contrast to recalcitrant C (e.g., humus) that has a turnover time of several hundreds to thousands of years. Reactive carbon originates from the various fractions of SOM. These fractions include fresh organic material, soil microbial biomass, particulate organic matter, and other easily metabolized organic compounds, such as carbohydrates (sugars) and proteins (amino acids), as well as C loosely bound to soil minerals. Because of its relatively short turnover time, RC is more sensitive to management changes that affect soil C in agro-ecosystems than TOC. Reactive carbon may be used as an indicator of the change produced by cropping and soil management practices that manipulate SOM content.

Soil electrical conductivity (EC) measures the ability of soil water to carry electrical current. Electrical conductivity is an electrolytic process that takes place principally through water-filled pores. Cations (Ca^{2+} , Mg^{2+} , K^+ , Na^+ , and NH_4^+) and anions (SO_4 , Cl , NO_3 , and HCO_3) from salts dissolved in soil water carry electrical charges and conduct the electrical current. Consequently, the concentration of ions determines the EC of soils. In agriculture, EC has been used principally as a measure of soil salinity (see Table 1); however, in non-saline soils, EC can be an estimate of other soil properties, such as soil moisture, soil depth, and nutrient content (e.g., nitrate concentration). EC is expressed in deciSiemens per meter (dS/m). Soils with EC values higher than 4mmhos/cm (4 dS/m) measured on their saturated extract are saline, and growth of crops sensitive to salinity is restricted on these soils. During recent years, sensors were used to map electrical conductivity and deduct nitrate concentration; Smith and Doran (1996) reported nitrate increases with increasing EC.

References

- Doran, J.W., and T.B. Parkin. 1994. Defining and assessing soil quality. *In* Doran et al. (eds.) *Defining Soil Quality for a Sustainable Environment*, pp. 3-22. SSSA/ASA, Madison, WI.
- Culman S.W., and others. 2011. Permanganate oxidizable carbon reflects a processed soil fraction that is sensitive to management. *Soil Science Society of America Journal* 76:494-504.
- Larson, W.E., and F.J. Pierce. 1994. The dynamics of soil quality as a measure of sustainable management. *In* Doran et al. (eds.) *Defining Soil Quality for a Sustainable Environment*, pp. 37-52. SSSA Special Publication 35:37-52.
- Lucas, S.T., and R.R. Weil. 2012. Can a labile carbon test be used to predict crop responses to improve soil organic matter management? *Agronomy Journal* 104:1160-1170.
- Oliver, D.P., R.G.V. Bramley, D. Riches, I. Porter, and J. Edwards. 2013. Soil physical and chemical properties as indicators of soil quality in Australian viticulture. *Australian Journal of Grape and Wine Research* 19:129-139.
- Pankhurst, C.E., B.M. Doube, and V.V.S.R. Gupta. 1997. Biological indicators of soil health: Synthesis. *In* C.E. Pankhurst, B.M. Doube, and V.V.S.R. Gupta (eds.) *Biological Indicators of Soil Health*.
- Smith, J.L., and J.W. Doran. 1996. Measurement and use of pH and electrical conductivity for soil quality analysis. *In* *Methods for Assessing Soil Quality*. Soil Science Society of America Special Publication 49:169-185.